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# Comparative evaluation of phosphorus losses from subsurface and naturally drained agricultural fields in the Pike River watershed of Quebec, Canada

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ABSTRACT

Phosphorus (P) is the limiting nutrient responsible for the development of algal blooms in freshwater bodies, adversely impacting the water quality of downstream lakes and rivers. Since agriculture is a major non-point source of P in southern Quebec, this study was carried out to investigate P transport under subsurface and naturally drained agricultural fields with two common soil types (clay loam and sandy loam). Monitoring stations were installed at four sites (A, B, C and D) in the Pike River watershed of southern Quebec. Sites A–B had subsurface drainage whereas sites C–D were naturally drained. In addition, sites A–C had clay loam soils whereas sites B–D had sandy loam soils. Analysis of data acquired over two hydrologic years (2004–2006) revealed that site A discharged 1.8 times more water than site B, 4 times more than site C and 3 times more than site D. The presence of subsurface drainage in sandy loam soils had a significant beneficial effect in minimizing surface runoff and total phosphorus (TP) losses from the field, but the contrary was observed in clay loam soils. This was attributed to the finding that P speciation as particulate phosphorus (PP) and dissolved phosphorus (DP) remained relatively independent of the hydrologic transport pathway, and was a strong function of soil texture. While 80% of TP occurred as PP at both clay loam sites, only 20% occurred as PP at both sandy loam sites. Moreover, P transport pathways in artificially drained soils were greatly influenced by the prevailing preferential and macropore flow conditions.



## 1. Introduction

Excessive phosphorus (P) loading into freshwater bodies has deteriorated water quality in many regions of the world. Intensive upstream agricultural land use activities tend to drastically increase P loading in downstream water bodies. Eutrophication has been identified as one of the leading threats to lake water quality worldwide (Harper, 1992). Negative effects of eutrophication include: dissolved oxygen depletion, increases in suspended solids, decreased light penetration, and reduction in aquatic flora and fauna species (Migliaccio et al., 2007). Algal mats get deposited at the surface, limiting the recreational use of the lake and facilitate growth of toxin producing cyanobacteria, which pollute the water bodies. These pollutants complicate the water treatment process, often rendering the lake water unsuitable for human consumption.

In response to elevated P concentrations in water bodies, various management strategies are being practiced around the world. The use of nutrient management plans and beneficial management practices are being promoted in North America. In addition, many regions use a modified version of the P-Index, which is used as a field scale tool to determine the risk of P loss from agricultural lands. There are many versions of the P-Index, developed specifically for a certain region; however, they all tend to be similar. Site factors such as soil characteristics, slope, soil test phosphorus (STP) concentration, percent P saturation ($P_{sat}$), fertilization practices, tillage practices, cropping patterns and distance of field to the nearest watercourse are typically included in the model (Sharpley et al., 2001). Tools such as the P-Index have been made available along with the development of hydrological and water quality models at the field, watershed and basin scales. Models such as ANSWERS (Beasley et al., 1980), CREAMS (Knisel, 1980), EPIC (Williams et al., 1984), GLEAMS (Leonard et al., 1987), AGNPS (Young et al., 1987), and SWAT (Arnold et al., 1998; Gollamudi et al., 2007) have all been used to simulate hydrology and P transport at different scales.

Traditionally, it was believed that P loss from agricultural landscapes occurred primarily during surface runoff events and very little was lost through subsurface drainage. However, research investigations have revealed that the subsurface drainage systems in agricultural fields also discharge significant phosphorus quantities under a wide range of soil characteristics and

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management practices (Gardner et al., 2002; Beauchemin et al., 2003). In a study performed by Heckrath et al. (1995), total P concentrations of 2.75 mg $L^{-1}$ were measured in subsurface drainage waters in an alkaline clay soil.

P losses from clay soils predominantly occur as particulate phosphorus (PP). Uusitalo et al. (2001) reported that the PP loss from a clay soil in Sweden was about 92% of the total phosphorus (TP) loss for both surface runoff and subsurface drainage. Migration of PP in heavy clay soils could be attributed to extensive macropore development that allows the movement of sediment and PP through the soil profile and into the subsurface drainage system. Besides clay soils, P losses on light textured soils have also been observed, in which the dissolved phosphorus (DP) concentrations are significant on over-fertilized soils where the P adsorption capacity is low (Nelson et al., 2005).

A review of literature on P losses from agricultural fields has revealed that research investigations on P dynamics under artificial subsurface drained conditions have been published (Enright and Madramootoo, 1994, 2004; Jamieson et al., 2003). However, there is a lack of research reports on the comparative evaluation of P loss from naturally drained and subsurface drained agricultural fields under similar agricultural and hydrologic settings. A comparative analysis could thus assist in evaluating the impact of subsurface drainage on overall P loss, and in developing a better understanding of P transport pathways. In view of the above, this study was undertaken with the objective of comparing P transport under subsurface drained and naturally drained fields for two soil textural classes (clay loam and sandy loam) in the Pike River watershed region of southern Quebec.

## 2. Materials and methods

### 2.1. Study area and research sites

The experimental sites were comprised of four single farm fields located approximately at a distance of 5 km west of the town of Bedford, Quebec. Bedford is located at a distance of 70 km southeast of Montreal and lies in the Pike River watershed (Fig. 1). The delineated area of the Pike River watershed is 629 $km^2$, spanning over the Quebec–Vermont border (Jamieson, 2001). The four fields (referred to as sites A, B, C and D) were situated on privately owned farm lands within a 3 $km^2$ radius of each other. The location of the fields within the Pike River watershed and the Missisquoi Bay is shown in Fig. 1.

Sites A and B have subsurface drainage installed, whereas sites C and D are naturally drained. The tile drainage systems at sites A and B were constructed with 11 cm diameter plastic corrugated lateral pipes and 21 cm diameter outlets. The outlets were clay tiles at site A and corrugated plastic at site B. The tile drain lateral spacing was 10 m at site A and 13 m at site B. The drains were

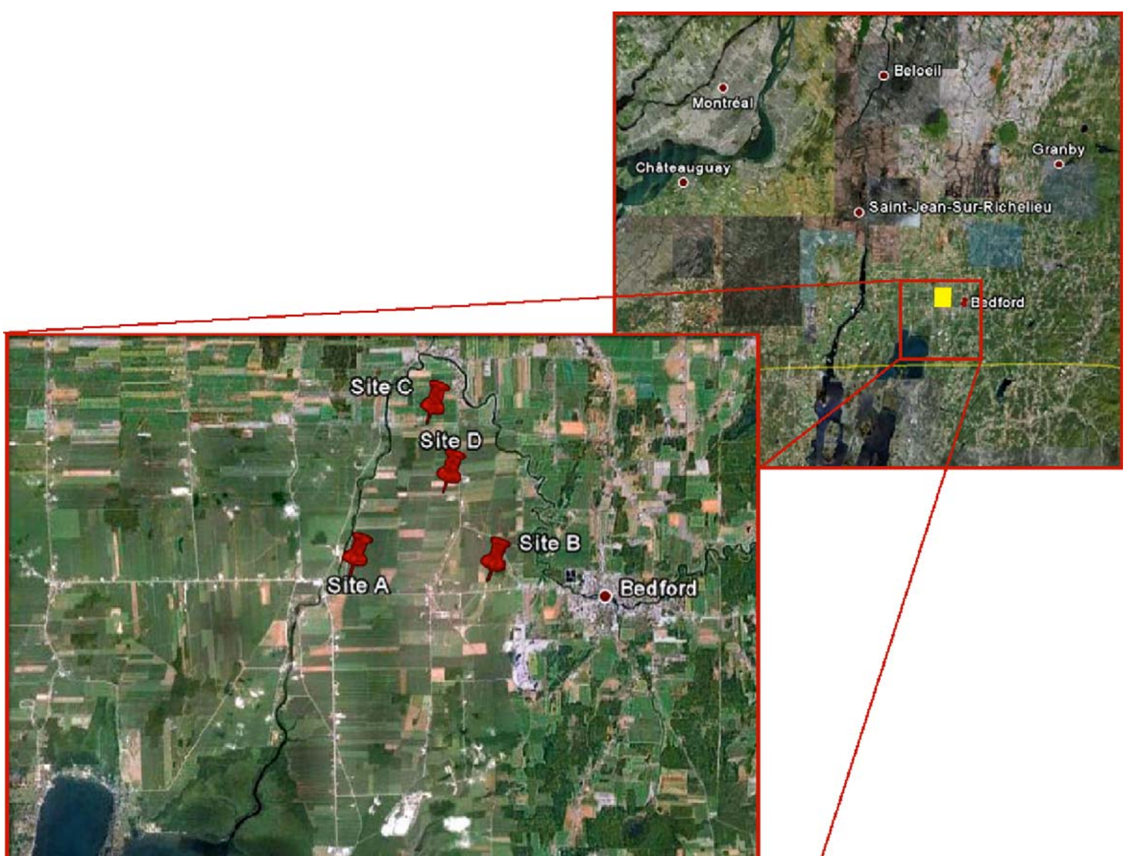


**Fig. 1.** Location of the four field sites within the Pike River Watershed of Southern Quebec, Canada (extracted from Google Earth on 05 November 2009).